

TITLE: LARGE AREA SMART PIEZOELECTRIC AND PYROELECTRIC SENSORS

Contract: DAJA 45-93-C-0017
(R & D 6980-EE-01)

Accession For	
NTIS	CRA&I <input checked="" type="checkbox"/>
DTIC	TAB <input type="checkbox"/>
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Justification <i>per form 60</i>	
By _____	
Distribution / _____	
Availability Codes	
Dist	Avail and/or Special
<i>A-1</i>	

SEVENTH INTERIM REPORT

Received 2 Feb 95

DTIC
ELECTE
FEB 28 1995
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DTIC QUALITY INSPECTED

January, 1995

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1. Introduction

In the sixth interim report progress was reported on the preparation of the ferroelectric ceramic calcium modified lead titanate (PTCa) via the sol-gel method. Pure lead titanate (PT) being difficult to pole due to a large tetragonality (c/a ratio) gives way to PTCa which by the addition of calcium to the crystal lattice reduces the c/a ratio, consequently making the ceramic easier to pole. The advantages of sol-gel production of the ceramic over other conventional methods include ceramics produced with high purity and homogeneity, small grain size ($\approx 1\mu\text{m}$ diameter) with narrow spread of sizes and the ability to be produced at lower temperatures.

The present report provides an account of the embedment of a composite material transducer within an E-glass reinforced epoxy laminate structure for use as an in-situ AE sensor, strain gauge or ultrasonic detector / transmitter for NDT techniques. It is envisaged that by embedding a transducer within a structure it may be used as an 'early warning' device, which would warn against potential failure of the structure. Another way of thinking is that the transducer while being used in a sensing mode can then be used in an actuating mode by use of a feedback circuit thus for example being used to damp out any unwanted vibrations of the structure.

2. Fabrication and Embedment of Piezoelectric Transducer

For Embedment of the thin film composite sensor within a laminate structure a number of factors have to be considered. These factors being

1. The total thickness of the laminate structure, i.e. number of plies.
2. Orientation of the individual plies within the structure.
3. Orientation of the plies in close contact with the composite film.
4. Material used for the electrical contacts to the electrodes of the transducer.

The laminate structure consists of a number of layers or plies of pre-impregnated glass-fibre material. This material consists of parallel glass fibres in an epoxy matrix. The orientation of the plies can take on either of two directions with respect to the fibre direction. These orientations are described as 0° or 90° with respect to an arbitrary orientation. A typical laminate structure would have a thickness of 6 or 8 plies with relative orientations of say $(0, 0, 90, 90, 0, 0) = [0_2/90]_2$ for a 6 ply laminate and $(90, 0, 0, 90, 90, 0, 0, 90) = [90/0_2/90]_2$ for an 8 ply laminate. The relative orientation of the plies is not critical but they should be such that the laminate structure is symmetrical about the neutral axial plane to avoid distortion during the curing process.

The composite film should be placed between two plies of the same orientation to avoid damage to the film due to local distortions of the laminate structure during curing. Electrical contact to the transducer from the 'outside world' can be made through a number of ways i.e. wires, conducting epoxy channels or metal foil strips. These contacts should protrude to the edge of the laminate structure via the inter ply planes and run parallel to the direction of the fibres. Electrical contact to the electrodes on the composites surface is ensured by the use of silver loaded paint (silver dag).

For test purposes a laminate structure of approximately 20cm^2 was fabricated in the laboratory. This structures was constructed on 20cm^2 plates which had been wrapped in aluminium foil to prevent adhesion of the laminate structure to the metal

plates. Layers of E-glass pre-impregnated ply were individually laid onto the plates to produce a $[0_2/90]_2$ orientation of 6 plies. The composite film was placed between two similarly orientated plies i.e. between plies no. 1 & 2. Once the structure had been built up another plate covered with aluminium foil was placed on top of the whole and the arrangement was then placed into a thermally controlled mechanical press. The laminate structure was cured at 100°C with enough pressure to hold the structure flat.

The transducer was fabricated from a composite material of PTCa / P(VDF-TrFE) with a ceramic volume fraction of 65%. The material was pressed in a temperature controlled mechanical press to a thickness of approximately $130\mu\text{m}$. Electrode areas of $3\text{cm} \times 4\text{cm}$ were deposited on each face and the thin film was poled in a DC field of 20MVm^{-1} .

Once the laminate structure had cured it was removed from the assembly and the aluminium foil peeled away. An electrical BNC connection was made to the contacts for monitoring of the transducer signal. Figure 1 shows a schematic diagram of the laminate structure.

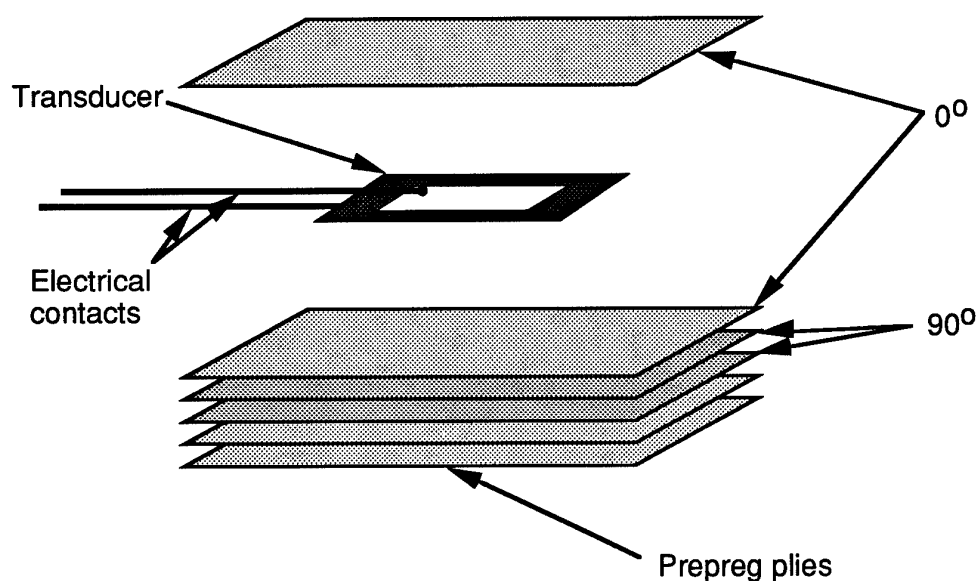


Fig. 1: Exploded view of a laminate structure containing a composite transducer.

The performance of the embedded transducer was evaluated by comparison of its response in pulse-echo mode and AE detection mode to a commercially available AE transducer (PAC R15). This sensor has a piezoelectric lead-zirconate-titanate (PZT) ceramic element with a resonant frequency of 150KHz .

3. Pulse - Echo Mode of Operation

The principle of the pulse-echo method for the NDT of materials is based on the detection of a reflected ultrasonic pulsed wave, usually in the form of a damped oscillation generated by a probe, which propagates through the specimen with a velocity, c , corresponding to the material concerned. If the transmitted pulse strikes

an obstacle such as an inhomogeneity the pulse will be reflected and, if this is not too large, the remainder will travel on to a boundary of the specimen which will then be reflected back to the receiver. From the time, t , taken to receive the reflected signal after being transmitted the distance, d , from the transmitter of any reflector can be calculated from

$$\frac{2d}{t} = c \quad \text{or} \quad d = \frac{ct}{2}.$$

If there were a number of transducers located at various situations around the specimen the location of any reflector could then be found by triangulation methods.

Pulse-echo mode of operation was performed by exciting one sensor (either the commercial or the embedded sensor) with a commercial ultrasonic pulser/receiver [PAR SPIKE 150 PR] producing a 150V pulse with a rise time of 5ns and recording the response of the other sensor on a digital storage oscilloscope (DSO) [Gould 4050]. The pulse repetition rate could be continuously varied from 1kHz to 10kHz and the DSO was triggered by the external trigger output of the pulser.

The commercially available sensor was placed on the outside of the laminate structure and a silicon vacuum grease was used to ensure good transmission of acoustic energy. Because of the close proximity of the two sensors the embedded sensor was electrically screened by wrapping the laminate structure in aluminium foil, which was then earthed so as to eliminate any electrical noise being picked up by the detecting sensor.

The trace from the DSO was downloaded onto a PC for printout and further analysis. Figures 2 & 3 show the response of the commercial and embedded sensors respectively while the other transducer is being excited by the pulse.

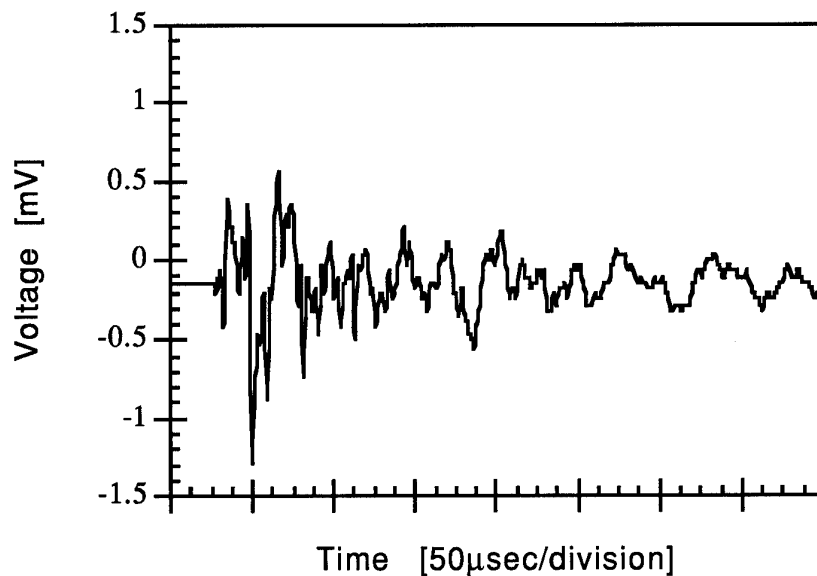


Fig. 2. Commercial sensor response with embedded sensor transmitting.

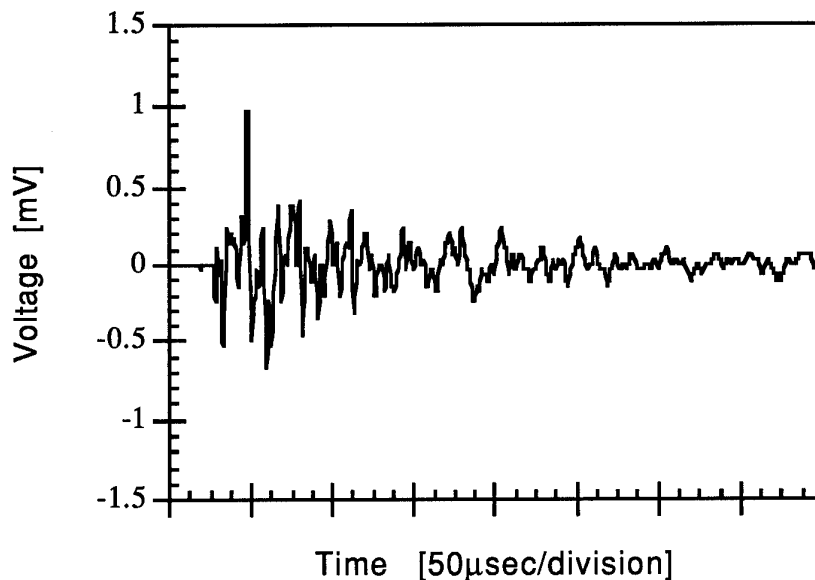


Fig. 3. Embedded sensor response with the commercial sensor transmitting.

As can be seen from figures 2 & 3 the response of the embedded sensor gives a comparable response to the commercial sensor.

4. AE Detection

Acoustic emission (AE) is the elastic energy that is spontaneously released by materials when they undergo deformation. An acoustic emission sensor is used to detect dynamic motion resulting from acoustic emission events and to convert the detected motion into a voltage-time signal. AE detection differs from most other NDT method's by the fact that the energy that is detected is released from within the test object rather than being supplied externally and also by its capability of detecting dynamic processes associated with the degradation of structural integrity.

AE monitoring of fibre reinforced composite materials has proven quite effective for the detection and location of fibre breakage, delaminations and other types of structural degradation. Attenuation of acoustic signals in fibre reinforced materials is much higher than in other materials such as metals, therefore, AE monitoring of these materials requires sensor spacing much closer together.

The performance of the embedded sensor to detect acoustic emission was compared to that of a commercially available sensor (PAC R15). A lead break source was used to produce the required AE signal. This source was located 8.5cm distance from the embedded sensor and 8.5cm distance from the commercial sensor. A 2H pencil lead of diameter 0.5mm protruding 6.7mm from a convex plastic receptacle was used to produce the AE source by levering, and subsequently breaking, the pencil lead against the surface of the laminate.

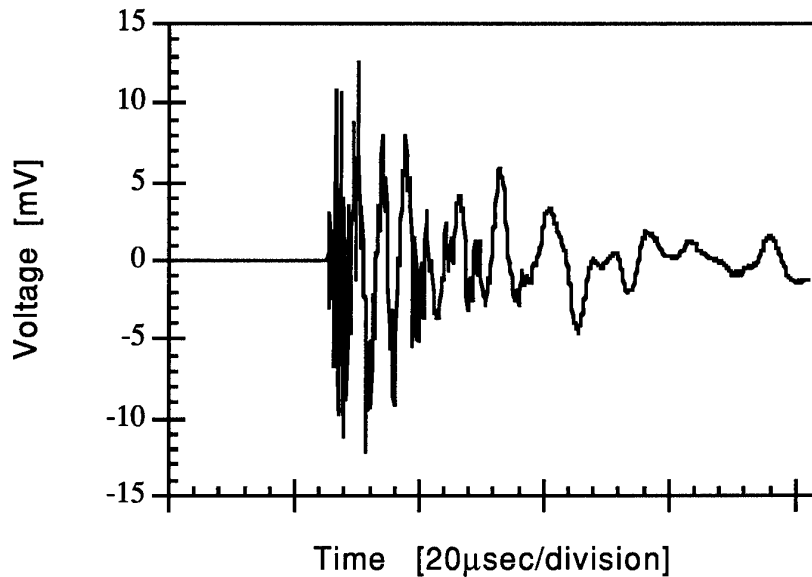


Fig. 4. Commercial sensor response to a lead break AE source. Trace taken by connecting the sensor directly to the $1\text{M}\Omega$ input of the DSO.

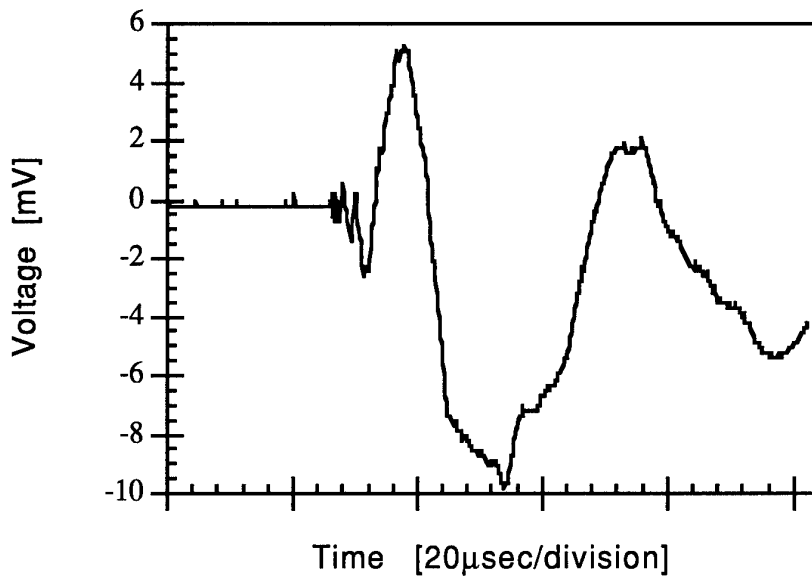


Fig. 5. Embedded sensor response to a lead break AE source. Trace taken by connecting the sensor directly to the $1\text{M}\Omega$ input of the DSO.

The commercial sensor was mounted with silicon vacuum grease couplant. Both sensors were connected to PAC 1220A preamplifiers with 100-300KHz filters. AE

data were gathered via two channels of a PAC 3000/3104 AE system. Data on the number of hits, event duration, counts, energy, amplitude and rise time were recorded.

The sensors were connected directly to a digital storage oscilloscope (Gould 4050) and their digitised traces were downloaded to a PC. Figures 4 & 5 show the direct output from the two sensors averaged over 8 AE detection's. These are the signals which are analysed by the AE system.

The average results of the measurements of the AE parameters of the embedded sensor are compared to the average results of the commercial sensor as given from the AE system are shown in table 1, the units being arbitrary.

	Embedded	Sensor	Commercial	Sensor
	threshold 03, gain 40	threshold 02, gain 40	threshold 05, gain 09	threshold 06, gain 09
Duration	148.4	218.1	369.5	464.3
Count	12.4	18.9	28.4	27.1
Energy	9.1	11.1	46.1	60.1
Amplitude	51.6	51.7	97.1	96.8
Rise Time	32.8	36.2	38.5	54.2

Table 1. Average response values for the embedded sensor compared to the commercial sensor, units are arbitrary.

As can be seen from table 1 the measured AE parameters of the embedded sensor while not as high as the commercial sensor, are still satisfactory for an AE sensor used in applications where only higher amplitude signals are of interest. The advantage being the built in location enabling testing of the material whilst the structure is in active use.

5. Further Work

Further progress in techniques to embed composite sensors made from a ceramic and an epoxy will be towards co-curing of the composite film with the epoxy of the laminate structure. By the use of conducting epoxy to form channels for the electrical contacts and also the electrodes on the surfaces of the transducer material, it is envisaged a laminate structure consisting of minimal foreign materials with polymer crosslinks formed between the glass-fibre matrix and the composite matrix. If these techniques work we may have totally integrated sensors within laminate structures with minimal inherent weaknesses due to the inclusion of alien materials providing sensor placement without detrimental effects to the laminate strength.

The modelling of the embedded sensor by use of electrical equivalent circuits and finite element analysis will produce information needed to improve the response qualities of these sensors.